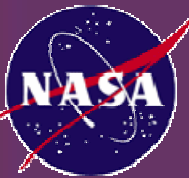
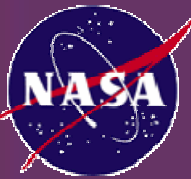


# **JCAA/JGPP Lead-Free Solder Testing for High Performance Applications**

**Thermal Cycle Testing:  
-55°C to +125°C**

**Dave Hillman  
Rockwell Collins**





# **Outline:**

- **Background**
- **Test Vehicle and Components**
  - **Thermal Cycle Protocol**
  - **Statistical Results**
- **Physical Failure Analysis Results**
  - **Additional Test Results**



## Objective:

Joint DoD-NASA-OEM project to provide baseline data to allow eventual qualification and validation of lead-free solder alloys for use in manufacture and repair of electronic equipment

## Scope:

- The interconnection of components to substrates with a lead free solder alloy
- Test for functional (electrical) reliability, not integrity
- Indirectly test effectiveness of repairing Pb-containing PWBs with Pb-free solder
- Test board to reflect many of circuits now on defense/space systems



# Project Participants

**DoD/NASA Facilitation  
(originally JG-PP; now JCAA)**

DoD MAJCOMs, Depot Process Owners

U.S. Original  
Equipment Mfrs.  
and  
Electronics  
Materials Suppliers

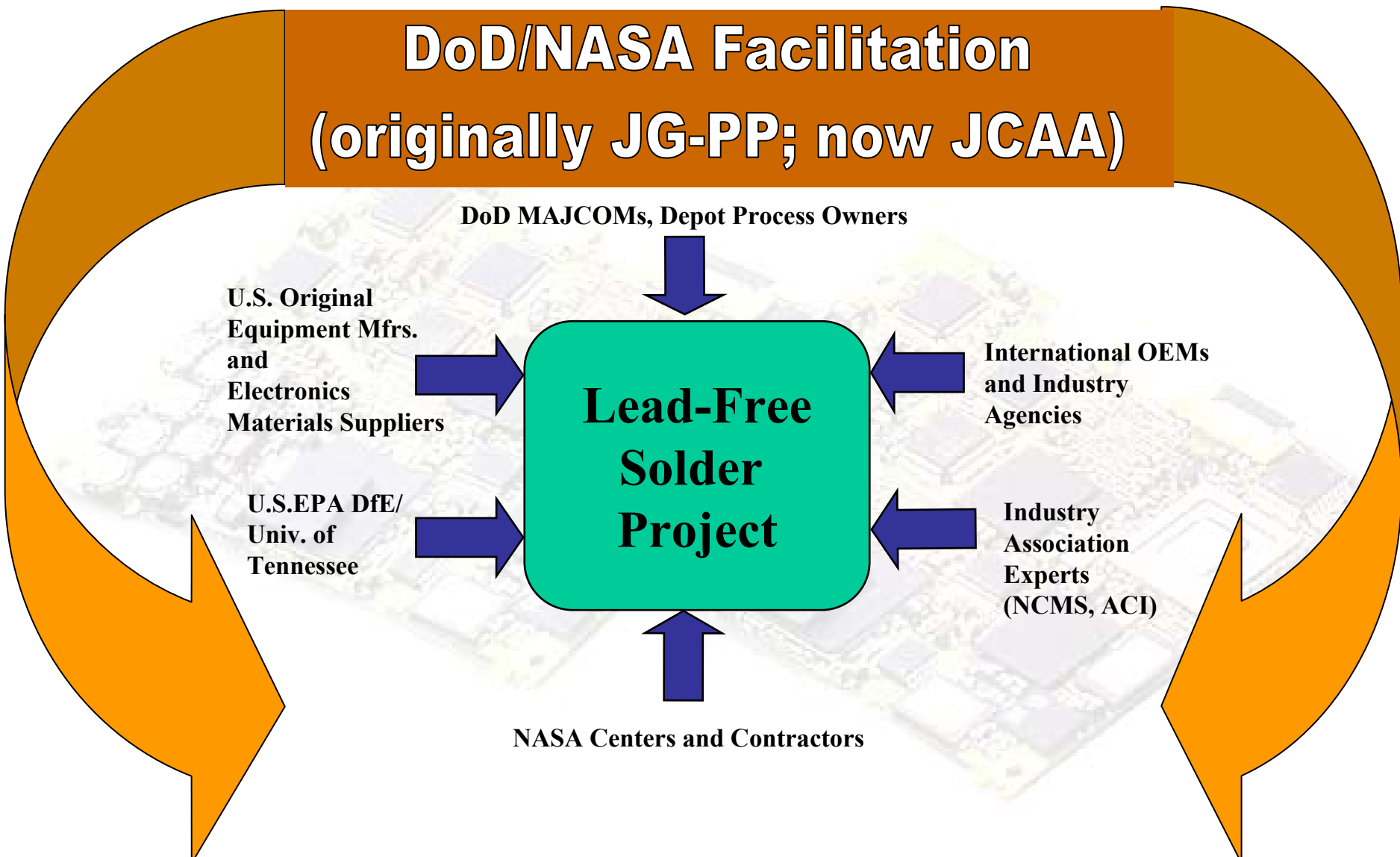
U.S.EPA DfE/  
Univ. of  
Tennessee

**Lead-Free  
Solder  
Project**

International OEMs  
and Industry  
Agencies

Industry  
Association  
Experts  
(NCMS, ACI)

NASA Centers and Contractors



## **Test Vehicle & Solder Alloys:**

- **Sn3.9Ag0.6Cu (SAC)** for reflow and wave soldering
- **Sn3.4Ag1.0Cu3.3Bi (SACB)** for reflow soldering
- **Sn0.7Cu0.05Ni (SNIC)** for wave soldering
- **Sn37Pb (SnPb)** for reflow and wave soldering
- **Manufactured PWBs**
- **FR4 per IPC-4101/26** with a minimum Tg of 170°C with an immersion silver surface finish.
- **Reworked “Legacy” PWBs**
- **FR4 per IPC-4101/21** with a minimum Tg of 140°C with a hot air, solder leveled (HASL) surface finish



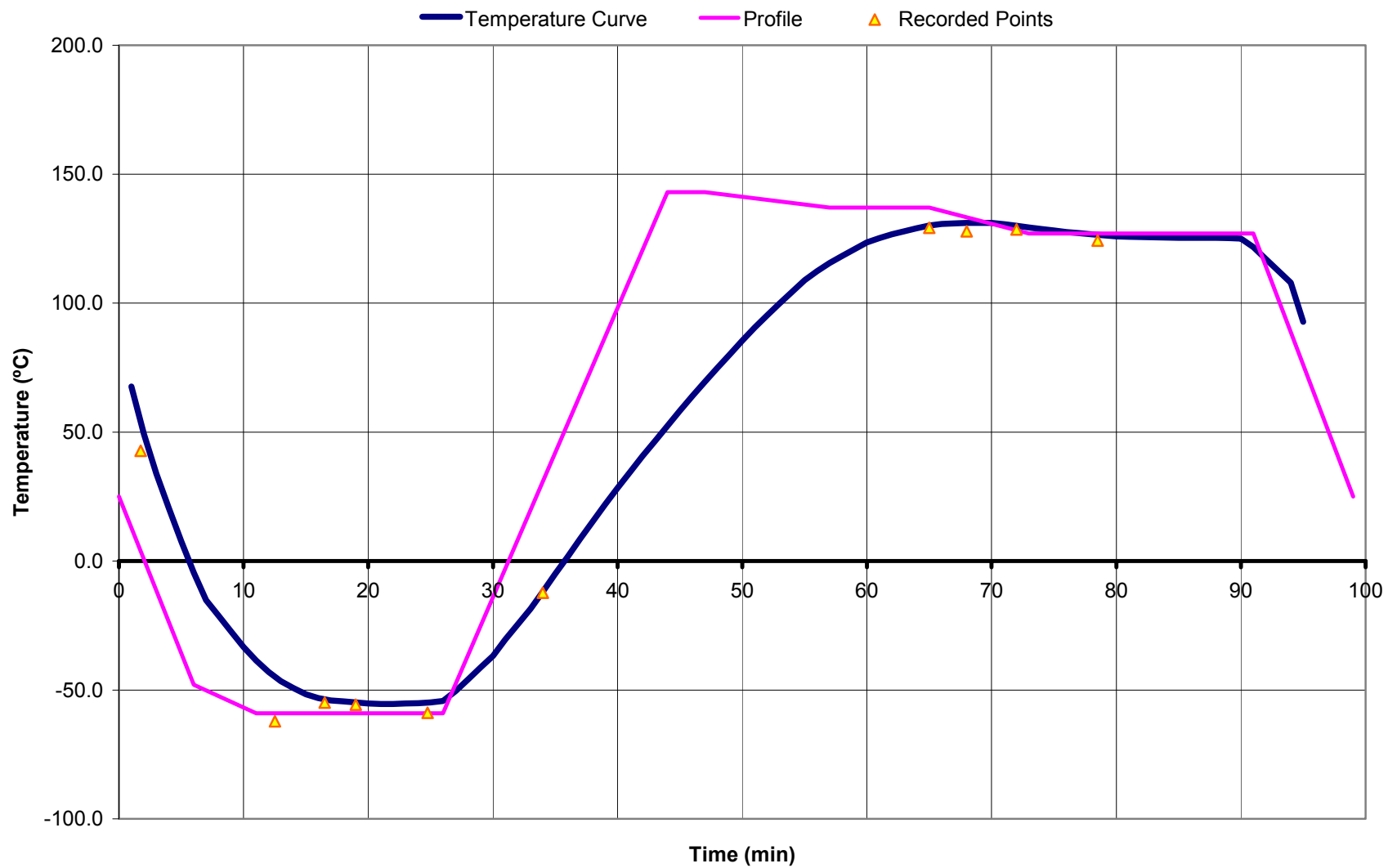
# **Test Vehicle Components & Finishes:**

<b>Component Type</b>	<b>Component Finish</b>
<b>CLCC -20</b>	<b>SnPb</b>
	<b>SnAgCu</b>
	<b>SnAgCuBi</b>
<b>PLCC-20</b>	<b>Sn</b>
<b>TSOP-50</b>	<b>SnPb</b>
	<b>SnCu</b>
<b>TQFP-144</b>	<b>Sn</b>
<b>TQFP-208</b>	<b>NiPdAu</b>
<b>BGA-225</b>	<b>SnPb</b>
	<b>SnAgCu</b>
<b>DIP-20</b>	<b>Sn</b>
	<b>NiPdAu</b>
<b>0402 Capacitor</b>	<b>Sn</b>
<b>0805 Capacitor</b>	<b>Sn</b>
<b>1206 Capacitor</b>	<b>Sn</b>
<b>1206 Resistor</b>	<b>Sn</b>

# Thermal Cycle Testing Methodology:

- In accordance with IPC-9701
- Temperature Extremes: -55°C and +125°C
- Temperature Ramp: 5°C-10°C per minute maximum
- Temperature Dwells: 10 minutes @ -55°C  
30 minutes @ +125°C
- Continuous Monitoring with Event Detector:
  - An Event = channel resistance exceeded 300  $\Omega$  for longer than 0.2  $\mu$ sec within a 30-second period
- A failure was defined when a component either:
  1. 15 consecutive maximum resistance events,
  2. 5 consecutive detection events within 10% of current life, or
  3. Became electrically open

Profile Control Chart







# Thermal Cycle Results:

- **4743 Total Thermal Cycles Completed**
- **12 months of Testing !!!**

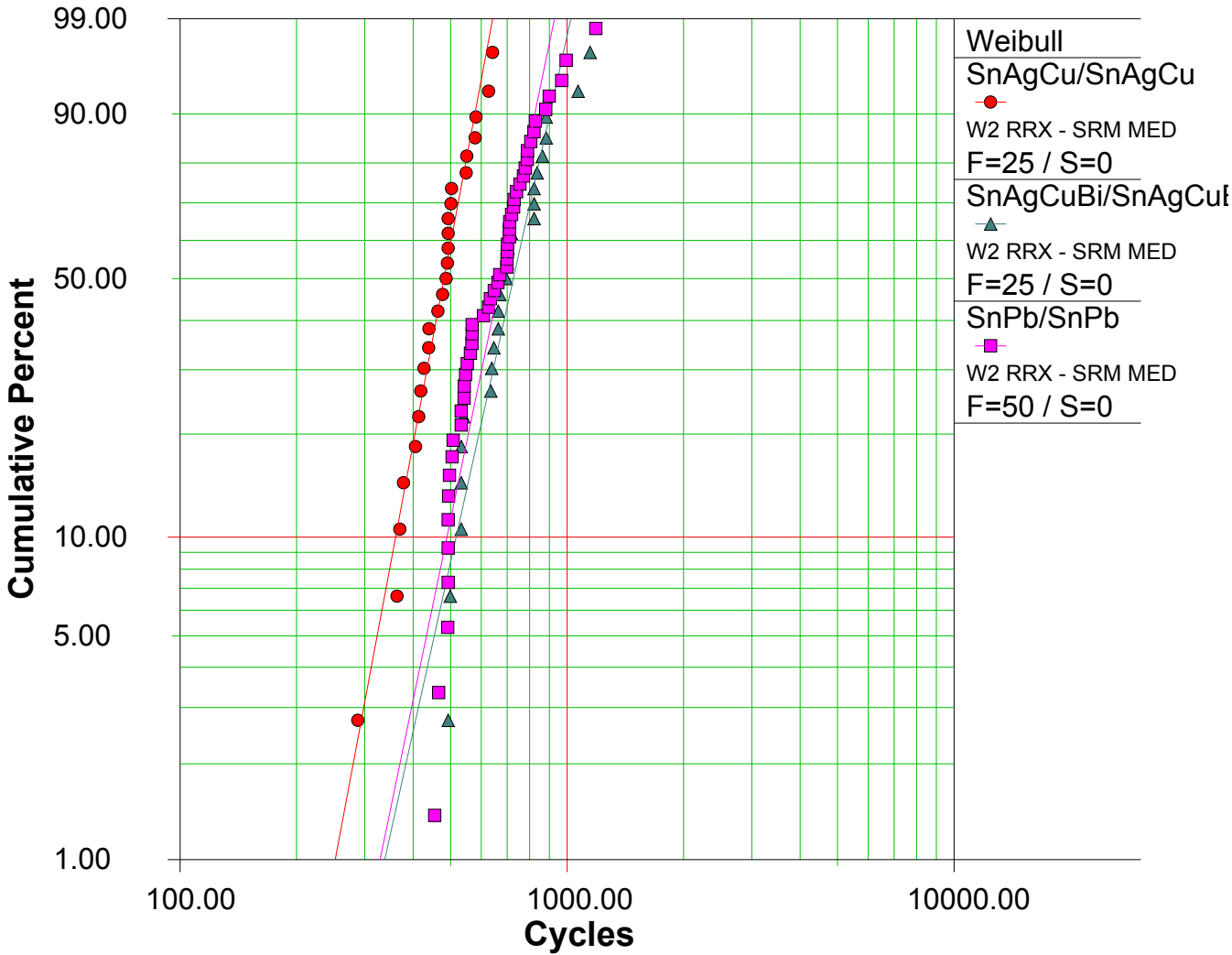
<b>Component Type</b>	<b>Total Failures</b>	<b>Total Population</b>	<b>Percent Failed</b>
BGA 225	257	300	85.7
CLCC 20	300	300	100
PDIP 20	24	300	8
PLCC 20	8	150	5.3
TQFP 144	136	150	90.7
TQFP 208	110	150	73.3
TSOP 50	296	300	98.7

# Thermal Cycle Results:



# Thermal Cycle Results:

## CLCC test results - Manufactured test vehicles (170°C Tg)

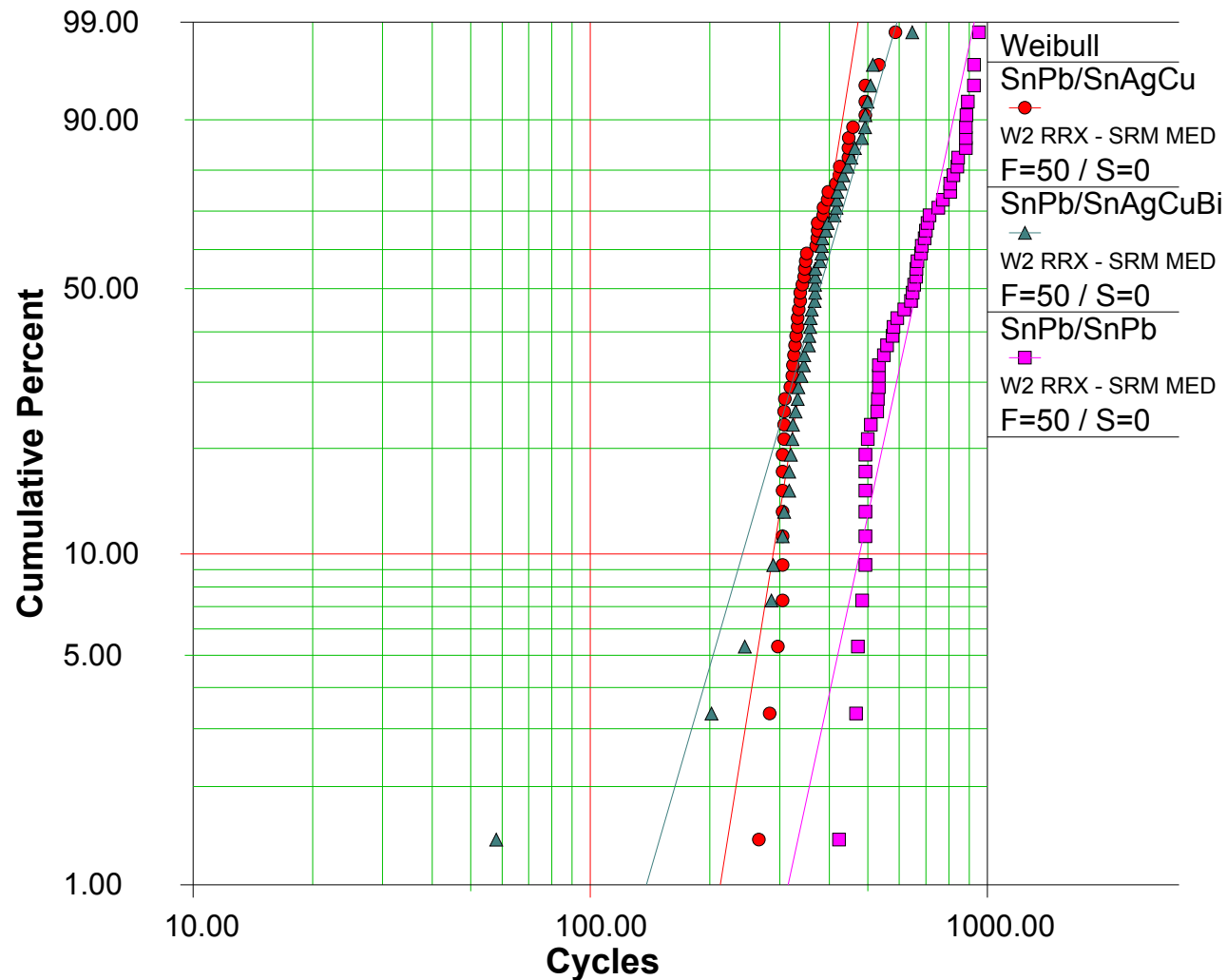


$\beta_1=6.5409, \eta_1=508.6653, \rho=0.9864$   
 $\beta_2=5.5317, \eta_2=776.3182, \rho=0.9453$   
 $\beta_3=5.9047, \eta_3=716.4935, \rho=0.9326$

Key: Solder Alloy/Component Finish

# Thermal Cycle Results:

## CLCC test results: Legacy test vehicles (140°C Tg)

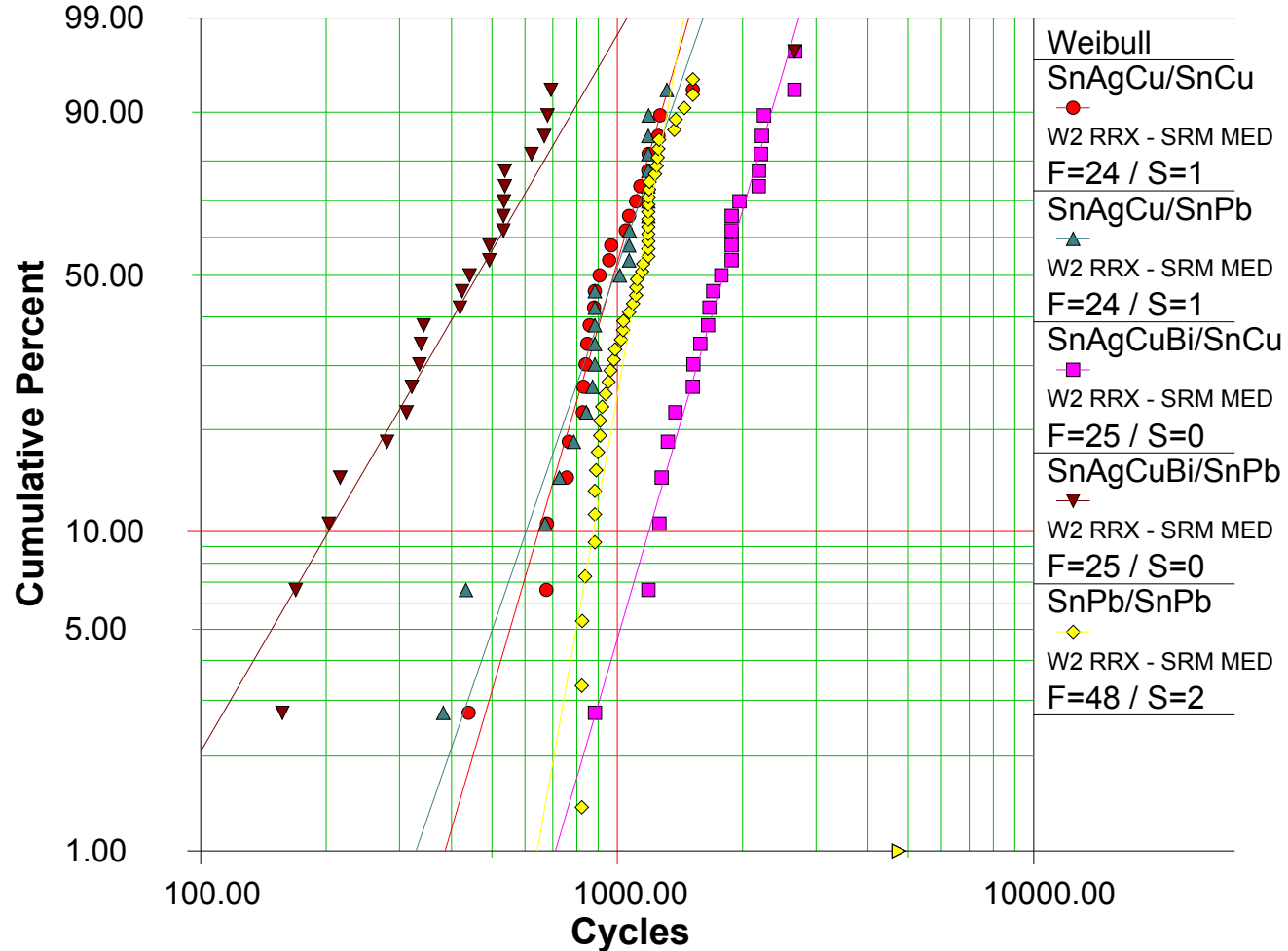


$\beta_1=7.6691$ ,  $\eta_1=387.3908$ ,  $\rho=0.8914$   
 $\beta_2=4.2149$ ,  $\eta_2=412.5278$ ,  $\rho=0.8758$   
 $\beta_3=5.6773$ ,  $\eta_3=708.6388$ ,  $\rho=0.9368$

Key: Solder Alloy/Component Finish

# Thermal Cycle Results:

## TSOP test results: Manufactured test vehicles (170°C Tg)



$\beta_1=4.5501, \eta_1=1061.7576, \rho=0.9732$

$\beta_2=3.8599, \eta_2=1082.2162, \rho=0.9642$

$\beta_3=4.5553, \eta_3=1950.6106, \rho=0.9890$

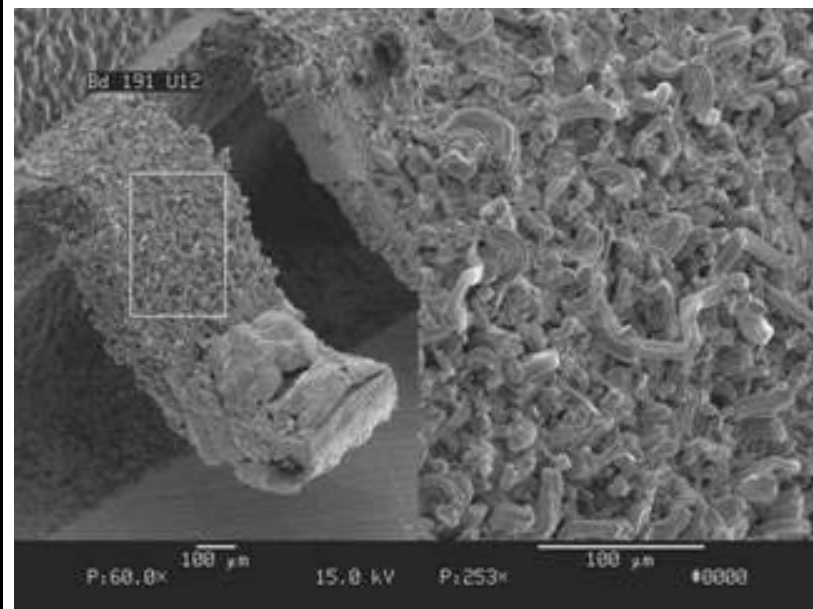
$\beta_4=2.2892, \eta_4=542.1344, \rho=0.9096$

$\beta_5=7.5694, \eta_5=1179.9001, \rho=0.9443$



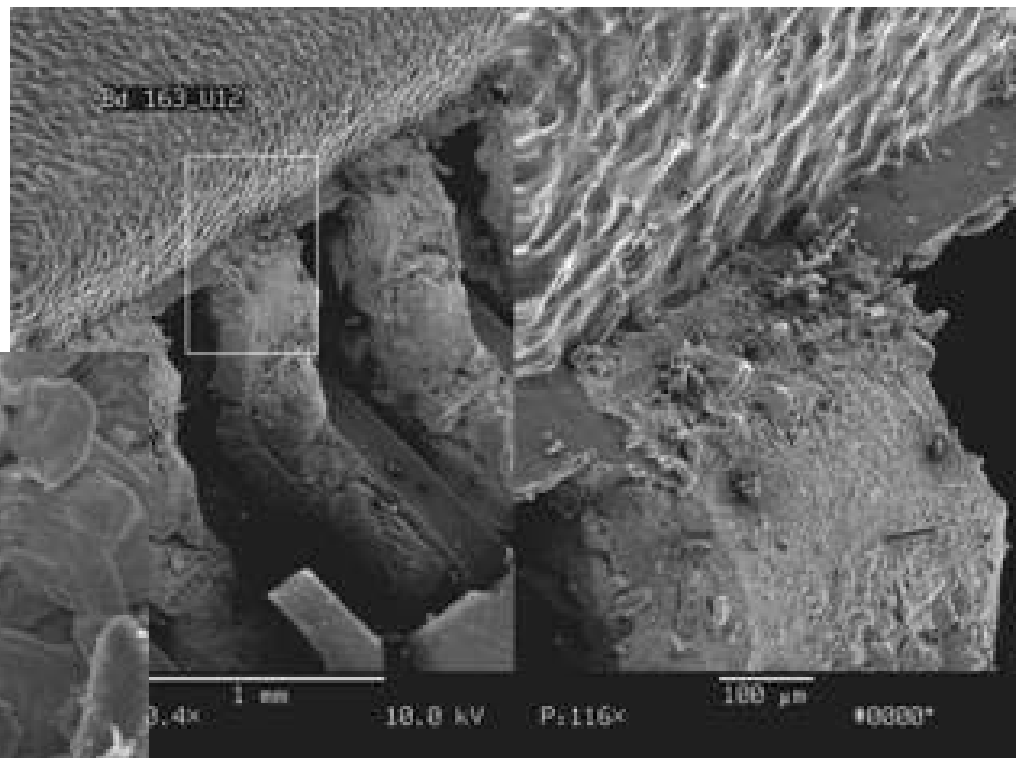
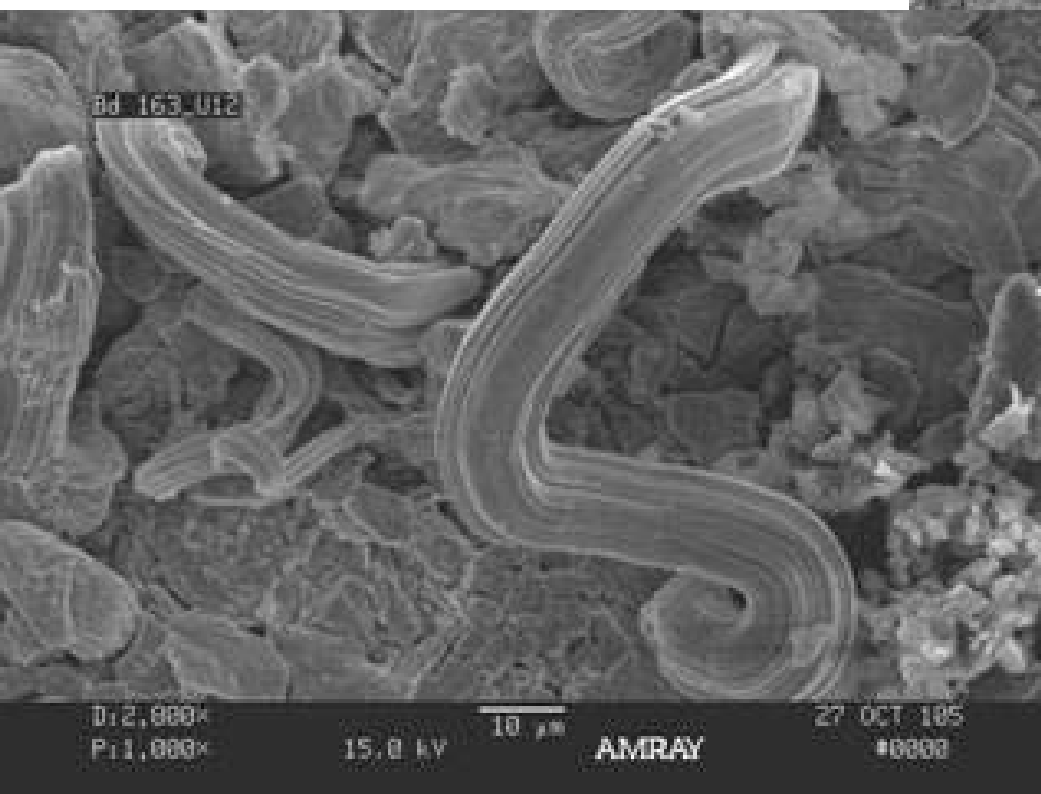
# Failure Analysis Results: Components/Finishes:

Component Type	Component Finish
CLCC -20	SnPb
	SnAgCu
	SnAgCuBi
PLCC-20	Sn
TSOP-50	SnPb
	SnCu
TQFP-144	Sn
TQFP-208	NiPdAu
BGA-225	SnPb
	SnAgCu
DIP-20	Sn
	NiPdAu
0402 Capacitor	Sn
0805 Capacitor	Sn
1206 Capacitor	Sn
1206 Resistor	Sn



# Failure Analysis Results:

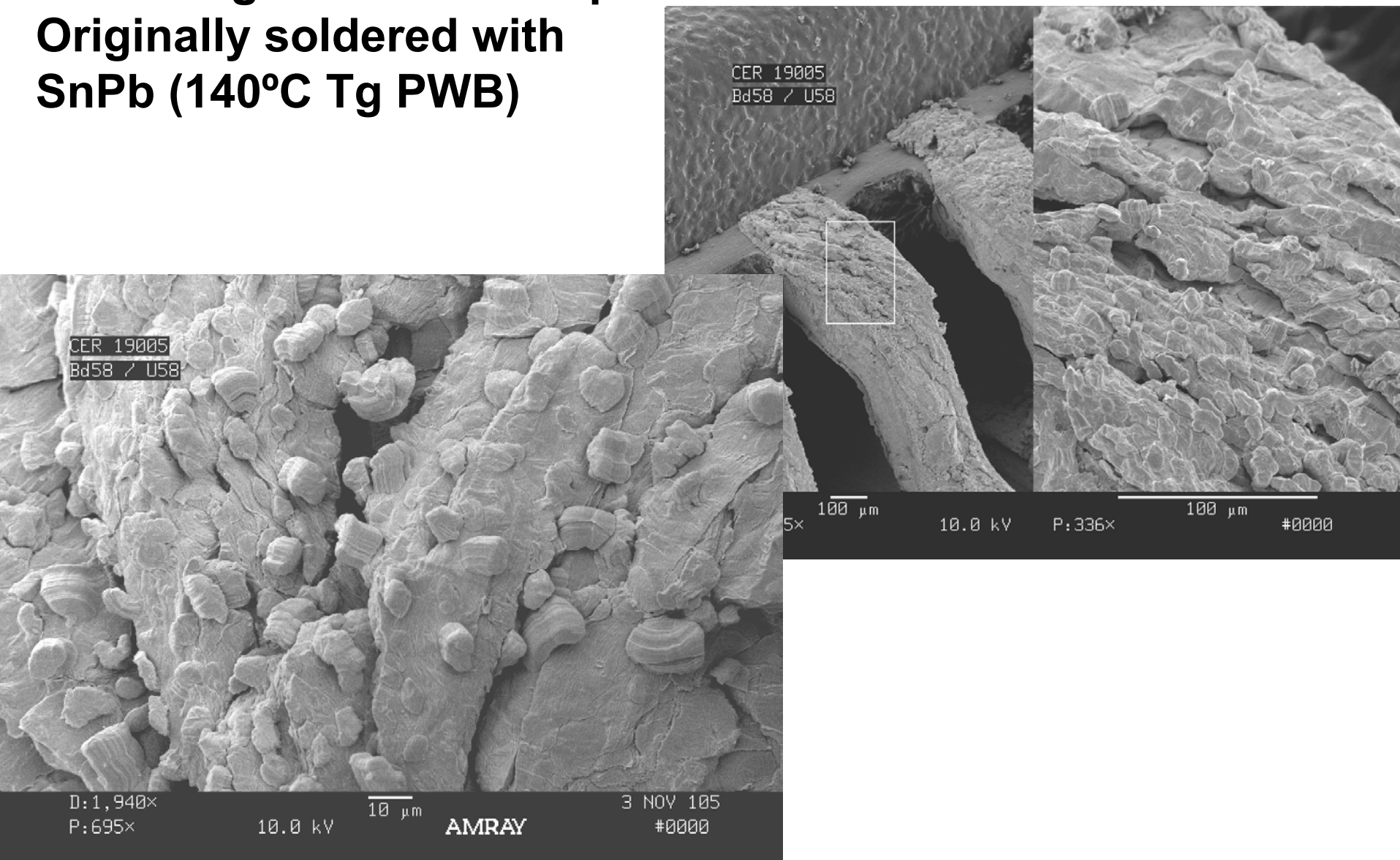
**SEM image of TSOP component with SnCu surface finish –  
Originally soldered with  
SnPb (140°C Tg PWB) then  
manually reworked  
with SAC**





# Failure Analysis Results:

**SEM image of TQFP component with Sn surface finish –  
Originally soldered with  
SnPb (140°C T<sub>g</sub> PWB)**

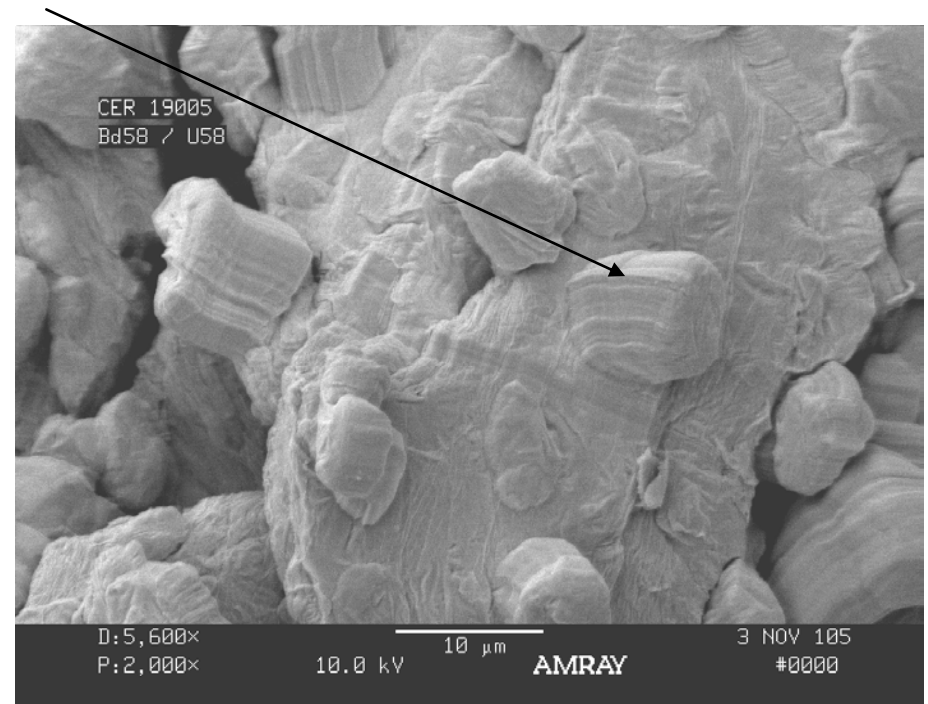
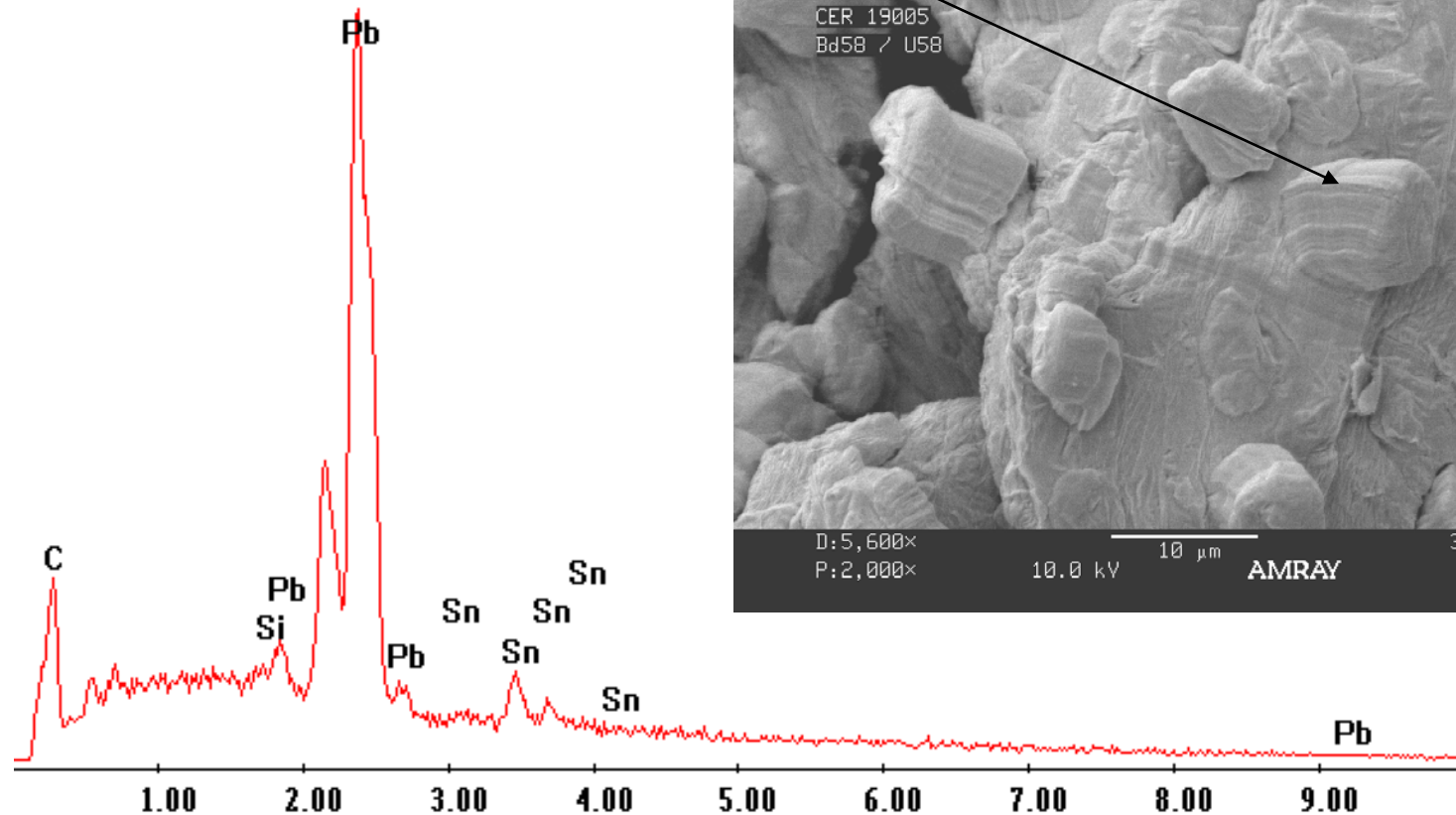


# Failure Analysis Results:

**SEM image of TQFP component with Sn surface finish –  
Originally soldered with SnPb (140°C T<sub>g</sub> PWB)**

Y:\DLK's\19005\bd58\_w2.spc

Label A: CER19005: Bd58 / U58 / Whisker 2



# Failure Analysis Results: Tin Whisker Summary

Component Type	Component Finish	Whisker Observations	Typical Whisker Diameter	Typical Whisker Length	Maximum Length Observed
TSOP	SnPb	Significant Whiskering Observed	8 $\mu\text{m}$	5 - 20 $\mu\text{m}$	50 $\mu\text{m}$
	SnCu	Significant Whiskering Observed	8 $\mu\text{m}$	10 - 30 $\mu\text{m}$	120 $\mu\text{m}$
DIP	Sn	No Whiskers Observed	NA	NA	NA
PLCC	Sn	No Whiskers Observed	NA	NA	NA
TQFP	Sn	Sporatic Whiskering Observed	8 $\mu\text{m}$	8 - 12 $\mu\text{m}$	12 $\mu\text{m}$
Note: Whiskers observed with severely twisted/contorted shapes or with stubby shapes					

**Note: No Tin Whiskers were observed on any of the other component/surface finish combinations**

# **Additional Thermal Cycle Results:**

- **Extensive Failure Analysis Effort Complete**
  - **FA Topics: Tin Whiskers, Pb Contamination, Tin Pest, Copper Pad Dissolution, Interface Voids, Fillet Lifting, Shrinkage Voids, Failure Crack Location, Laminate Defects, Microstructure Uniformity**
- **JCAA/JGPP Consortia Joint Test Report (JTP) Will Contain Final Report and Data**
- **Weblink:**  
**[http://www.jgpp.com/projects/projects\\_index.html](http://www.jgpp.com/projects/projects_index.html)**

# Questions ???



**What are you doing to save time?**